How to calculate PV performance ratio and performance index

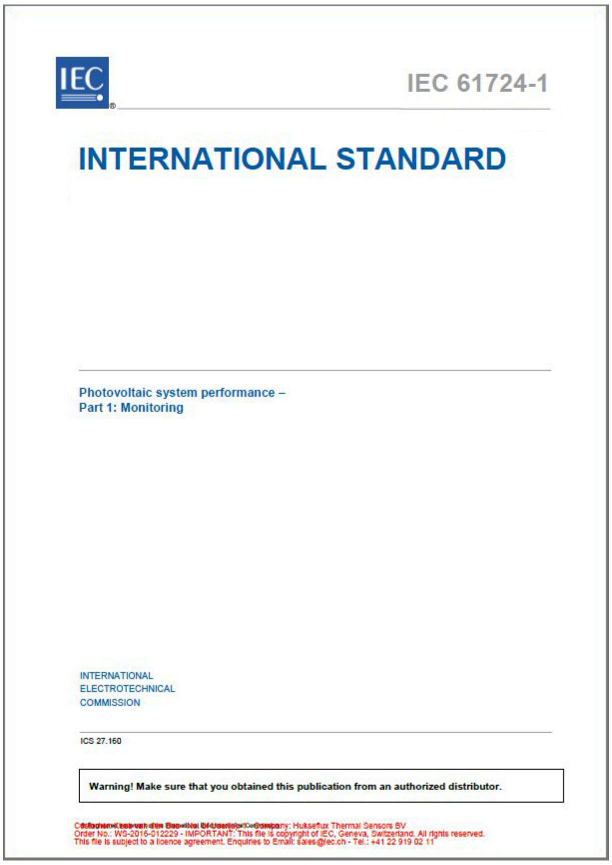
According to the latest IEC 61724 standard series

The new IEC 61724 "Photovoltaic system performance" series of standards is the best available source that defines parameters such as "performance ratio" and "performance index". The purpose of this document is to clarify the logic behind IEC 61724 and its vocabulary. For the sake of brevity we do not mention all parameters and performance metrics. If you want to know more: purchase the IEC standards.

Introduction

IEC recently revised the standard for PV system performance testing. It is now a series of 3:

- IEC 61724-1, "*monitoring*" giving requirements for measuring
- IEC TS 61724-2 "*capacity evaluation method*" defining performance analysis based on the monitoring data over a short period of several sunny days
- IEC TS 61724-3 "*energy evaluation method*" defining performance analysis based on the monitoring data over a long period of 1 year or longer than that.



IEC 61724-1

INTERNATIONAL STANDARD

Photovoltaic system performance –
Part 1: Monitoring

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 27.160

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Figure 1 *Cover of the new IEC 61724-1 standard, published in February 2017*

Purpose of performance monitoring

IEC gives as possible purposes of PV performance monitoring:

- identification of performance trends in an individual PV system
- localization of potential faults in a PV system
- comparison of PV system performance to design expectations and guarantees
- comparison of PV systems of different configurations
- comparison of PV systems at different locations

Important factors in PV performance

The most significant and direct impacts on PV performance are:

- in-plane irradiance received by the PV array
- the PV cell temperature
- shading losses due to soiling or snow

Secondary factors that may enter the assessment are:

- clipping of the inverter, if the inverter cannot output more than a certain power in [W]
- curtailment; the network may not accept the available power
- losses (see next pages)

Figure 2 *PV system performance monitoring with pyranometers measuring GHI and POA*

Performance model, ratio, index

IEC uses the following definitions:

- **performance model** gives a mathematical description of the electrical output of the PV system as a function of meteorological conditions, the system components, and the system design. This model is typically agreed upon in advance by the stakeholders of the test.
- **predicted output** is the output for a given period as calculated using the performance model based on historical weather data.
- **expected output** is the output calculated using the performance model when entering measured weather data.
- **rating** performance as specified by the manufacturer, usually confirmed via the name-plate on the panel, or as agreed upon by a supplier, typically under reference conditions such as STC Standard Test Conditions.
- **performance ratio (PR)** is the ratio of measured output to expected output for a given reporting period based on the system name-plate rating
- **performance index** is the ratio of measured output to expected output for a given reporting period based on a more detailed model of system performance than the performance ratio
- **PPI** performance based on power, Power Performance Index
- **EPI** performance based on energy, Energy Performance Index

IEC 61724-1:2017(E)

This standard outlines requirements for measuring equipment (sensors), methods, and terminology for performance monitoring and analysis of photovoltaic (PV) systems. In addition, it serves as a basis for other standards which rely upon the data collected, such as 61724-2 and 61724-3.
It addresses sensors, installation, and accuracy for monitoring equipment in addition to measured parameter data acquisition and quality checks (calibration and cleaning), calculated parameters, and performance metrics.

IEC TS 61724-2:2016(E)

This standard defines a procedure for measuring and analysing the power [W] production of a photovoltaic system with the goal of evaluating the quality of the PV system performance.
It does so by comparing the measured power produced to the expected power on a few relatively sunny days. The point of this test is that it can be done fast. The minimum test duration is 2 days, provided that these days meet certain boundary conditions.
Panels have to be "nominally clean", operation has to be unconstrained (no clipping), the panels should be unshaded. Irradiance must be between pre-defined limits such as 0.5 to 1.2 TRC (Test Reference Condition) or for example above 450 W/m^2. In this test we accept a higher uncertainty than the test of IEC 71724-3. Hukseflux suggests working with irradiances of > 600 W/m^2 only.
The expected angle of incidence of the solar beam then is around 52°, which is lower than the Brewster's angle for glass, which is 56°. Working at high angles of incidence reduces uncertainty due to the variation of reflectance, and reduces the uncertainty of the POA irradiance measurement,
A typical test outcome is a PPI involving a temperature correction and includes an expanded uncertainty.

IEC TS 61724-3:2016(E)

This standard defines a procedure for measuring the energy [kWh] production of a photovoltaic system and for comparison to expected electrical energy production under actual weather conditions over a year or more. A practical reporting period is 1 or multiple years.
The test offers a full assessment of electricity production. It covers all operating conditions, and offers insight in performance under all weather conditions, or times of the year. It also offers a picture how other factors, such as maintenance, plant degradation and hardware failures impact the plant performance.
The expected electrical energy is calculated with a model; a simple temperature corrected PR can still have misleading variations due to seasonal effects and local conditions. More complex models, such as the Sandia PV Array Performance Model (SAPM) the System Advisor Model (SAM) and PVsyst, take into account measured weather conditions along with estimates for soiling and degradation.

In IEC 61724-3 the energy production is characterized separately for times when the system is operating (available) and times when the system is not operating (unavailable).
A typical test outcome is a set op performance indicators, most importantly a yearly “in service EPI” including an estimated expanded uncertainty.

Figure 3 *Hukseflux model SR30 (at the front) is the first heated pyranometer, compliant with the requirements of IEC 61724-1 for Class A monitoring systems. It overcomes a typical problem in freezing conditions seen with the non-heated pyranometer at the back: ice accumulation on the pyranometer dome surface reduces data availability.*

Parameter definition in IEC

- **in-plane irradiance G_i or POA**: [W/m^2] the sum of direct, diffuse, and ground-reflected irradiance incident upon an inclined surface parallel to the plane of the modules in the PV array, also known as plane-of-array (POA) irradiance
- **H_i** : [kWh/m^2] in-plane irradiation
- **E_A** : [kWh] Energy output from PV system (DC)
- **E_{out}** : [kWh] Energy output from PV system (AC), so after the inverter
- **P_0** : [kW] array power rating (DC) the total DC power output of all installed PV modules at the power rating reference condition, assumed to be standard test conditions (STC reference values irradiance 1 000 W/m^2, at normal incidence, PV cell temperature 25 °C), typically as given on the name plate.
- **$P_{0, AC}$** : [kW] array power rating (AC)

Yields and yield losses

Models and test reports may involve yields and losses. Yields are ratios of an energy quantity to the array power rating P_0. They indicate actual array operation relative to its rated capacity. Yields have units of [kWh/kW], where units of kWh in the numerator describe the energy output and units of kW in the denominator describe the system power rating. The yield ratio indicates the equivalent amount of time during which the array would be required to operate at P_0 to provide the particular energy quantity measured during the reporting period.

- **Y_A**: [kWh/kW] PV array energy yield (DC per rated DC)
- **Y_f**: [kWh/kW] final system yield (AC per rated DC)
- **Y_r** : [kWh/kW] reference yield (DC)

Yield losses are calculated by subtracting yields. The yield losses also have units of [kWh/kW]. They represent the amount of time the array would be required to operate at its rated power P_0 to provide for the respective losses during the reporting period.

- **L_C**: [kWh/kW] array capture loss (**$Y_r - Y_A$**)
- **L_{BOS}**: [kWh/kW] balance of system (BOS) loss (**$Y_A - Y_f$**)

Clipping and Curtailment

In some cases the operation of inverters is a bottleneck. They can only supply power within a certain range. If the power hits the upper limit of this range, we call this condition “constrained operation”. In case of clipping: consider reporting performance metrics based on E_{out} as well as E_A.
Curtailment may involve periods of reduced grid/load demand or availability. The system generates power but cannot supply it to the network. For purposes of performance assessments and performance guarantees, irradiation and yield sums should be calculated with such periods excluded.

Traditional Performance Ratio

Indicates the overall effect of losses on the system output and is the quotient of the system’s final yield Y_f to its reference yield Y_r

$$PR = Y_f / Y_r = (E_{out} / P_0) / (H_i / G_{i,ref})$$

Traditional PR neglects array temperature, typically resulting in seasonal variation.

Temperature-Corrected Performance Ratio

Seasonal variation of the traditional PR is removed by calculating a temperature-corrected performance ratio:

$PR'_{STC} = (E_{out} / C_k\ P_0) / (H_i / G_{i,ref})$

with

$C_k = 1 + \gamma \times (T_{mod,k} - T_{reference})$

Using 25 °C as T_{ref} gives PR'_{STC}.
This term C_k corrects for difference between actual temperature and STC temperature used for power rating. The value of γ is usually negative and of the order of -0.3%/K.

Module temperature is correlated with irradiance, so in case the performance is modelled; you must use a weighted average. PV panels may rise up to 20 °C above ambient temperature.

Cell temperatures are typically 1 °C to 3 °C higher than the temperature measured on the module's rear surface, depending on the module construction. The temperature difference may best be estimated as a function of irradiance, using the thermal conductivity of the module materials. Suggestions for this can be found in IEC 61724-2 Annex A.

Annual temperature-Corrected Performance Ratio

Approximates the value that would be obtained for traditional PR evaluated over one full year, by compensating for seasonal variation.

Digital twins

Analysis is increasingly based on modelling of the entire power plant using more complex models, such as the Sandia PV Array Performance Model (SAPM), the System Advisor Model (SAM) and PVsyst. These models no longer work with G_i , but with GHI as input.

Where can I order the standards?
The standards can be purchased from the IEC Webshop.

Use of pyranometers

General recommendations for choice, calibration and cleaning of pyranometers of IEC 61724-1 are summarised in a separate note.

The Hukseflux pyranometer model SR30 is compatible with the requirements of Class A monitoring systems.

IEC 61724-2 recognises in 6.5.3 that special attention should be given to the irradiance data. It recommends performing a regular quality check using a comparison of multiple instruments on a clear day. In particular false readings due to instrument shading should be removed from the dataset. At the location of all POA measurements, IEC 61724-3, clause 5 requires measurement of the local albedo to verify that it is representative of the albedo of the total power plant, fits the assumptions made in modelling, and to use the measurement in the uncertainty evaluation of the performance test.

About Hukseflux

Hukseflux Thermal Sensors makes sensors and measuring systems. Our aim is to let our customers work with the best possible data. Many of our products are used in support of energy transition and efficient use of energy. We also provide services: calibration and material characterisation. Our main area of expertise is measurement of heat transfer and thermal quantities such as solar radiation, heat flux and thermal conductivity. Hukseflux is ISO 9001 certified. Hukseflux products and services are offered worldwide via our office in Delft, the Netherlands and local distributors.

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